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For processing companies, the synthesis and design of optimal industrial operations includes all the strategic and tactical decisions such as the selection of raw materials and products portfolio, as well as the synthesis and design of the processing network and the optimization of the material flows through it.

Recent development in process system engineering (PSE) focused on a class of multi-scale models (from meso to mega-scale), formulating them as Mixed Integer Non Linear Programming (MINLP) problems (Grossmann, 2005). As many contributions in the literature demonstrate, problems of this class are certainly non-trivial, where typical factors contributing to the increase in problem complexity are number of process alternatives considered, size and complexity of the process models used to describe the process alternatives and presence of recycles, bypasses and parallel processing. Several methods and solution strategies (e.g. model reformulation, problem decomposition, variable initialization and bounding) have been successfully proposed for the solution of complex network synthesis problems. These methods and tools are often tailor-made for the specific problem to be solved, and therefore their selection and implementation is not trivial and requires expert judgment.

In this contribution, we propose a systematic framework for the formulation and solution of processing network synthesis problem, and illustrate its application through the solution of industrial case studies, developed in collaboration with Alfa Laval. The key characteristic of the framework is to manage the complexity of the multi-scale problem through a systematic approach, in order to allow simple, efficient and robust formulation and solution of the problem. In the first step of the framework, the user is guided through the formulation of the problem. A superstructure containing all possible alternatives is generated, the objective function is selected, and all relevant data and models are collected, reconciliated and systematized in a database structure. All available engineering and commercial insights are translated in logical constraints aiming at excluding redundant solutions from the search space, that is, the superstructure. In the second step the formulated MINLP problem is analyzed to identify and suggest the most appropriate solution strategy.

One of the strategies employed in the framework is the incremental decomposition-based solution, the complexity of the formulated problem is decomposed, and a series of sub-problems with incremental levels of complexity is automatically generated. The generated sub-problems are then solved in a sequence, where a lower level sub-problem solution provides initialization and bounds to the higher level, until the full problem solution is obtained. Moreover, sensitivity analysis is used at each step, in order to prioritize the use of complex (non linear) models to describe only processes and phenomena which have a large impact on the overall objective, so to obtain a good tradeoff between model complexity and quality of the solution.

The proposed framework is applied to the formulation and solution of industrial process synthesis problems, in the field of edible oil production and refinement, wastewater treatment and biorefinery.Through the presentation of these industrial case studies, the features of the proposed framework are highlighted, and the complexity related to industrial application of process synthesis (large number of process alternatives, complex and non-linear models, presence of recycles, bypass and parallel processes etc.) is discussed.

References

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